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A STUDY OF SOME FACTORS INFLUENCING THE BOLT LIFT OF THE SPRINGFIELD RIFLE

by

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A STUDY OF SOME FACTORS INFLUENCING THE BOLT LIFT OF THE SPRINGFIELD RIFLE

Project KSX 100-41 Determination of the functioning cycle of the Cal. .30 semi-automatic rifle

Abstract

The bolt lift required to extract the cartridge case from the chamber of the Springfield was measured under various conditions in an effort to find ways of improving the extraction characteristics of the semi-automatic rifle under conditions of firing in a hot gun. Cartridges were soaked in the chamber for periods up to 4 minutes before being fired in a rifle heated by rapid fire. Bolt lift was found to be maximum for rounds fired immediately upon being chambered in a hot gun; it was somewhat lower for rounds soaked 4 minutes before being fired, but it was still much higher than for rounds fired in a cold gun or for rounds fired after being heated about a minute in a hot gun. Comparative tests were made using a worn gun and a relatively new one which showed that bolt lift tended to be lower in the worn one. An effort was made to measure the effect of clearance in the chamber on the bolt lift in a hot gun by firing minimum cartridges selected with an improvised gauge, but the results were inconclusive. Two modified bolts had no appreciable effect on the bolt lift. Piezo-electric gauge records were taken of rounds heated in an oven which showed that the high pressures developed by hot rounds are due to more rapid combustion of the charge in the normal way. A study of the tests suggests that the clearance of the round in the chamber should be a minimum and that the bearing of the cartridge in the chamber should be as long as possible. Comparison of the firings in the new and the worn Springfields leads to the interesting conclusion that extraction difficulties in a new rifle can be ameliorated by advancing the forcing cone to simulate the erosion present in an old gun.

indicate a condition like that reported at Frankford Arsenal, where it was found that when a round was left for 4 minutes in a rifle heated to about 135° C. in the region of the chamber and then fired there was serious difficulty in extracting the cartridge case. The divergence between the results obtained at the Proving Ground and at Frankford seemed to be due to the difference in the time of heating of the rounds. It was decided therefore to increase the time of heating of the ammunition in another test.

Table I shows also that increasing the pressure developed in the cartridge case tends to make extraction of the case more difficult.

Even when rounds were soaked 4 minutes in the hot Springfield, no condition that could be described as unusually difficult extraction was remarked (See table II). The highest bolt lift measured then was only 29 lbs. But it seemed that the good showing made by this particular rifle might have been owing to severe erosion of the barrel which prevented the development of pressures high enough to cause extraction trouble (See table VII).

For this reason hot gun tests were made again in which a comparatively new rifle (No. 142992) and the same ammunition (cal. .30 ball, M1, lot 1342) were used. The bolt lifts measured were then higher (See table III) although extraction was still not exceptionally difficult.

When it was deemed advisable to measure the bolt lift of a new rifle, it was also thought worth trying to find the variation in bolt lift, if any, caused by firing cartridges of minimum diameter, since the opinion had been expressed that clearance between the cartridge and the chamber tends to increase bolt lift, other things being equal. In order to permit the selection of such cartridges a gauge was improvised by cutting a section 3/8 inch thick from the chamber of a machine gun barrel. Measurements were made by inserting each cartridge in the hole in the gauge and measuring the distance to the gauge from the base of the cartridge with a depth gauge. Thus it was possible to rank the cartridges with respect to case diameters provided that the case of any cartridge was not deformed and that its base was at right angles to its axis.

The ammunition used in the test of minimum rounds was cal. .30 ball, M1, lot 1684, which was labeled High Extraction. The choice fell upon this lot because measurements showed that the average diameter of the cases of these cartridges was smaller than that of the ammunition previously used.

Table III contains the data of a test in which the regular ammunition (lot 1342) and the High Extraction ammunition were used in the same new rifle (No. 142,992). Both for cold rounds fired in a hot gun and for rounds soaked in a hot gun before being fired the bolt lift is higher for the lot 1684 ammunition. One case of really high bolt lift (92 lbs.) was observed in which the primer was blown. However, it does not follow that the increase in bolt lift was due only to increase in clearance between the round and the chamber as the metal of the lot 1684 cartridges may have been in a physical condition different from that of the lot 1342 ammunition or the charges in them may have developed higher pressures.

To eliminate the effect of possible differences between the lots maximum and minimum rounds were chosen from two hundred cartridges of lot 1342 which had been gauged. When these rounds were fired cold in the hot new Springfield, the minimum cartridges may have shown a tendency to give higher bolt lifts, but because of the variation of the temperature of the gun which is inherent in the method of heating employed an inference cannot be drawn with any assurance (See table IV).

To complete the comparison of the two Springfields the new rifle (No. 142,992) and the old badly eroded one (No. 1,180,858) High Extraction ammunition (lot 1684) was fired in the old gun. It is very interesting to note (See table V) that the highest bolt lift obtained for such a round soaked four minutes in the old gun was only 34 lbs., which is much less than the maximum of 94 lbs. obtained in the new rifle.

Table VI records data obtained with two modified bolts. One bolt had 0.01 inch cut from the faces of the locking lugs to increase the headspace. The ridge around the face of the other was relieved at an angle of 45° to permit greater lateral freedom to the base of the cartridge, the idea being that if the base of the case could flow more easily in this region the reaction on the rear of the chamber might be less. Inspection of tables III and VI shows that bolt lift may have tended to be higher with the modified bolts but again an inference cannot be drawn from the data with any confidence because of differences in gun temperature.

The experiments had made it clear so far that when a round is soaked in a hot rifle for about four minutes and then fired the effort required to extract the case is appreciably greater than that required to remove the case when a cold round is fired in a cold gun. Indeed, under certain conditions the case can be removed only with difficulty. To account for the higher bolt lift required to extract such rounds the hypothesis had been advanced that possibly conditions in heated cartridges favor the development of waves during combustion of the powder which have the effect of increasing the maximum pressure substantially above that which would be developed by normal burning of the charge, the greater pressure tending to increase the deformation of the cartridge case and thus make it more difficult to withdraw from the chamber. In order to get evidence of such pressure waves, if they occur, it was decided to make piezo-electric gauge records of rounds soaked in a hot gun and then fired. But further study showed that the gun itself could not be heated without injuring the gauge. Therefore it was necessary to heat the ammunition outside of the r_fle for these firings.

The ammunition was heated by bringing it up to temperature in an oven and holding it at temperature for at least a half hour. After it was heated, each round was removed quickly from the oven, chambered in the rifle, and fired immediately.

Although the temperatures of the rounds fired ranged from room temperature up to 136° C. (which is approximately the temperature of extensive hot round firings conducted at Frankford Arsenal) and the maximum pressures measured varied from 40,000 up to 75,000 lbs/in^2 (piezo-electric readings), in no case did the pressure record give evidence of a pressure wave which might reinforce the maximum pressure. Figures 1 to 6 are typical records. Table VIII is a record of the pressures obtained. Both copper pressure and piezo-electric gauge pressure were obtained for each round.

After each shot the ease with which the case was extracted was noted; arrangements for measuring bolt lift, however, had not been made. No extraction difficulties and no mutilated cases were observed until the two highest temperatures in the series of shots were reached. Then all three of the cartridges fired at 134° and 136° C. developed blown primers, and in each instance the head of the cartridge case was enlarged and grooved by expansion of the portion of the case not supported by the chamber. Two of these cases were extracted with the greatest difficulty by the bolt. In none of the previous firings in the Springfield was a cartridge case of this ammunition (lot 1342) expanded so much as the cases of these last three cartridges.

DISCUSSION OF RESULTS

Cold Rounds Fired in a Hot Gun

From the experiments it seems to be clear that any factor which increases the clearance of the case in the chamber tends to increase the bolt lift, too. If a cold round is fired in a hot chamber, the bolt lift is much greater than when a cold round is fired in a cold gun. On the other hand, if a round is left in the chamber for half a minute, which allows the case to become warm, the bolt lift is much less.

The following explanation is tentatively offered for the observed effect that the bolt lift is increased by increasing the clearance between the case and the chamber. When the charge is ignited and the pressure rises, the rear of the case is held firmly against the bolt by the pressure as soon as the bullet is forced out of the case, and the forward end of the case is held firmly in the chamber by the friction developed by the contact pressure*. Thus, as the pressure increases, the case is pinned at its base and also at its forward end, and during the increase

* A simple calculation shows that the pressure in the cartridge is probably about 2000 lbs/in^2 when the bullet leaves the case, as the force necessary to remove the bullet in the regular pull test averages about 130-140 lbs., it is believed. Some excess over the pressure equivalent to this pull is necessary to accelerate the bullet. Calculations based on an estimated modulus of elasticity of the brass in the case of 15,000,000 lbs/in^2 show that a pressure of about 2500 lbs/in^2 is necessary to get contact between the cartridge of maximum diameter and the chamber of minimum diameter. For these reasons it seems likely that the head of the cartridge is pressed against the bolt before the case grips the chamber wall.

in pressure it cannot contract longitudinally but is forced to expand lengthwise to a certain extent as a result of the extension of the chamber. If the case has clearance as the pressure rises, it expands radially until the clearance is taken up and then expands with the chamber. Since Poisson's ratio is positive, there will be as a result of the radial expansion a tendency for the case to contract longitudinally. However, the constraints on the case during the application of pressure to it are such that no longitudinal contraction can take place. Therefore there will be produced a longitudinal tension when the case is expanded by the powder pressure. After the pressure has fallen, the longitudinal tension will cause the case to contract lengthwise until the tension is relieved. This contraction will produce a further radial expansion which will tend to make the case stick in the chamber.

It seems plausible to suppose that the extent of this longitudinal contraction and additional radial expansion will increase with the clearance of the case in the chamber. If this assumption is correct, then the above description serves to explain the observed phenomenon that the bolt lift is increased as the clearance of the case increases with the temperature of the chamber. Of course the further assumption is tacit that the only important effect of heating the chamber is to augment its diameter.

There is another factor besides the increase of clearance which tends to increase the bolt lift for any cartridge, whether it is hot or cold, when it is fired in a hot gun. During the combustion of the charge very high temperatures are reached while conditions of turbulence and pressure promote the transfer of heat from the hot gases to the metal of the case. Therefore, there must be some expansion, or tendency toward expansion, which is due to the heat taken up by the case. Since the loss of heat by the case, other things being equal, depends on the temperature difference between the case and the chamber wall, the diminution of heat expansion by heat transfer from the case must be less, the hotter the gun is.

As mentioned before, for a round left in a hot gun even a fairly short time, half a minute, before it is fired, the bolt lift is less than when a cold round is placed in a hot chamber and fired immediately. This decrease in bolt lift is plausibly explained by the reduction in clearance between the case and the chamber, which decreases the permanent set the cartridge can taken. Since the coefficient of thermal expansion of the cartridge brass is about 50% greater than that of the barrel steel over the usual range of barrel temperature, the heating of the case must reduce the clearance in the chamber. Although the data shows that bolt lift increases again as the time of heating of the cartridge is increased, this effect cannot be due to thermal expansion of the cartridge, because calculation shows that the chamber and the case must be heated to about 400° C. to get contact in that way. It seems reasonable to infer that some other cause than thermal expansion of the case acts to increase the bolt lift for a round soaked about four minutes in a hot gun.

Hot Rounds Fired in a Hot Gun; Firings of Separately Heated Ammunition

An analysis of the deformation of the case of a cartridge heated in a hot rifle before being fired suggests ways in which the extraction problem in such a gun may possibly be ameliorated. When an unusually high pressure is developed in a cartridge, the portion of the case not supported by the chamber is expanded and a pronounced ridge appears near the base of the case which is caused by shearing of the cartridge on the breech end of the chamber; the expansion of the head enlarges the primer pocket, and the primer falls out or is merely loosened. Since the shearing of the case at the breech must tend to make the portion of the case in the chamber adjacent to the sheared section grip the wall, difficulty is experienced in extracting such rounds. The obvious palliative is to make the chamber as long as the functional requirements of the extractor will permit so that the shearing action will be resisted by a greater thickness of metal in the cartridge and the total pressure producing it will be less. Of some assistance, too, possibly, would be a small fillet at the breech to minimize the penetration of the case by the shoulder, although this would reduce the length of bearing of the case in the chamber.

From the firings of separately heated ammunition it seems quite probable that the high bolt lift required to extract cartridges that are soaked about four minutes in a hot gun is the result of the high pressures developed in them, which have been measured at the Proving Ground and at Frankford Arsenal, also. Furthermore, the piezo-electric gauge records of these rounds show that the high pressures are due merely to more rapid combustion of the powder in the normal way. This observation is interesting because the hypothesis was advanced at Frankford Arsenal (F.A. Small Arms Ammunition Dept. Conf. Report No. 68 P. 12) that conditions in a cartridge soaked in a hot gun favor the development of local pressure waves*. Of course heating the charge should be expected to increase the maximum pressure because it has long been recognized that preheating increases the reaction rate of processes such as the combustion of a powder.

It was remarked above that in none of the previous firings when cartridges were soaked and fired in a hot gun was a cartridge case of the ammunition lot used (lot 1342) expanded so much as the cases of the separately heated cartridges fired at the highest temperatures(134° and 136° C.) in a cold gun. This observation seems to indicate that conditions are more favorable to the development of high pressures when the ammunition is heated separately than when it is heated in a rifle that has been heated by rapid fire, and it appears that the reason is that the charge can be heated uniformly to a high temperature.

The importance of uniform heating becomes clear when it is remembered that the highest temperature to which any part of the charge can be heated is the ignition temperature of the powder. Thus the smaller the temperature differences in the charge, the higher may be the average temperature of the charge for a given limiting temperature. By heating the ammunition slowly in an oven this condition of minimum temperature differences in the charge was attained.

In this connection there has been advanced at the Proving Ground an hypothesis concerning the effect of clearance in the chamber on the pressure developed by a round soaked in a hot gun. When the temperature of the rifle is above the ignition temperature of the powder and there is little clearance between the cartridge and the hot chamber, conditions favor the heating of the powder in contact with the case to the ignition temperature because the resistance to the flow of heat from the barrel to the case is a minimum, and there is a good chance that this portion of the charge will ignite before the whole mass is heated evenly; experience shows that only moderate pressures are developed when a charge pre-ignites. As the clearance between the cartridge and the chamber increases, the air-space around the cartridge becomes larger. Since air is a relatively poor conductor of heat, the rate of flow of heat to the cartridge must decrease, other things being equal. If this is so, then the temperature gradient in the powder must also decrease, because the rate of flow of heat is proportional to the product of the

* It is probable that the "distinct band or mark approximately 0.1 inch in width impressed on the outside of the cartridge case within approximately 0.2 inch of the inside of the head" mentioned on p. 12 of the Frankford Arsenal report is attributable to local weakness of the case rather than to a local pressure wave of high intensity, because there seems to be a minimum in the Baby Brinell hardness curve in this region. (See Fig. 1 of F.A. S.A.A. Dept. Conf. Rep. No. 68).

conductivity and the temperature gradient, by Fourier's law; so the average temperature of the powder in a round of minimum diameter can be higher for a given limiting maximum temperature. Thus it follows that the charge in the cartridge of minimum diameter should be able to develop the highest pressure for a given limiting ignition temperature in a hot gun provided that it is left in the gun long enough and that the initial temperature is high enough. This seems to be another reason for keeping clearance between the cartridge and the chamber as small as possible; however, the reduction of extraction difficulties obtained by doing so must be paid for by an increased tendency toward pre-ignition.

Although confidential report No. 68 of the Frankford Arsenal Small Arms Ammunition Department (Rifle, U.S. Semi-automatic Cal. .30, Functioning of Weapon with Chromium Plated Chamber Heated to Temperatures Circa 150° - 275° F.) indicates the possibility of ameliorating extraction difficulties when rounds are soaked and fired in a hot gun by increasing the diameter of the chamber, consideration of the test conditions at Frankford Arsenal indicates that the results obtained at that establishment are not necessarily inconsistent with the hypothesis advanced above concerning the beneficial effect of decreasing the clearance in the chamber (beneficial as far as it concerns limiting the increase of maximum pressure due to increase in the average temperature of the charge). Since the gun temperature was practically constant and the heating period was fixed during the tests at Frankford Arsenal, an increase in clearance between the round and the chamber caused a decrease of the average temperature of the charge and hence the maximum pressure developed by it, because the rate of flow of heat to the cartridge was reduced by a thicker insulating blanket of air. Therefore it is to be expected that increased clearance between the round and the chamber will improve the extraction characteristics of a rifle heated for a fixed period by a device which keeps the chamber at a substantially constant temperature as the cartridge can take up less heat. It must be emphasized that conditions are quite different in a gun heated by rapid fire, because the temperature of such a gun is decreasing during the time that a round is in the chamber.

Perhaps a restatement at this point of the effect that decreasing the clearance of the cartridge in the chamber may be expected to have on the bolt lift when a round is soaked and fired in a hot gun will make the hypothesis clearer. The advantage of keeping the clearance between the cartridge and the chamber at a minimum is that it will keep the resistance to the flow of heat from the barrel to the cartridge at a minimum, too; the lower such resistance is, the steeper will be the temperature gradient in the charge for a given gun temperature, and the more probable will be its pre-ignition, which will tend to limit the average temperature of the charge and the pressure developed by it, and hence the bolt lift, provided that the initial temperature of the gun is high enough. At gun temperatures below the ignition temperature of the powder reduction of the clearance is a disadvantage as far as keeping down the average temperature of the powder is concerned, but as the temperature of the charge decreases, the pressure that it can develop decreases, too. The data obtained in the bolt lift tests tend to support the contention that decreasing the clearance will make extraction less difficult when rounds are left in the chamber of a hot gun, because the average bolt lift for rounds which pre-ignited is less than that for rounds fired at the end of a four minute heating period.

Besides being of some value in limiting the average temperature of the powder and therefore the maximum pressure developed by it, any decrease in the diameter of the chamber which is practicable should make the extraction of the case of a round fired immediately upon being chambered in a hot gun less difficult. This point is very important because examination of the test data shows that the extraction of such a cartridge may be expected to be more difficult than the extraction of the case of a cartridge which has soaked in the chamber for four minutes. Furthermore, in service cold rounds will be fired much more frequently in a hot gun than will rounds that have been soaked in a hot gun.

In view of the test experiences and the above considerations it appears that, other things being equal, bolt lift may be expected to be a minimum if the clearance between the cartridge and the chamber is a minimum and if the chamber is as long as proper functioning of the extractor will permit.

<u>Firings in Old and New Springfields</u>

The firings of both the lot 1342 and the lot 1684 ammunition show that bolt lift tends to be lower in the old Springfield rifle (No. 1,180,858) than in the comparatively new one (No. 142,992). It seems plausible to attribute the more favorable performance of the old gun to severe erosion of the barrel particularly in the region of the forcing cone, which prevents the development of pressures as high as those attained in the new one (See table VII). If such is the case, then the extraction characteristics of any new rifle can be improved through artifical aging of the barrel by removing enough metal to simulate the erosion present in an old gun.

Modification of Springfield Bolt to Increase Headspace

If clearance in the chamber is the most important factor influencing bolt lift, increase of headspace in service probably can never be great enough to affect extraction appreciably since an increase even as large as 0.01" cannot augment the clearance between the cartridge and the chamber by as much as 0.0002", because the taper of the Springfield chamber is only about 0.016 to 0.017 inch per inch. However, an increase in headspace brought about by removing metal from the bolt makes it possible for more of the base of the cartridge to protrude from the chamber during the development of pressure; such a condition would be expected to tend to cause higher bolt lift.

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Table I

Bolt Lift Test, August 31, 1936
Rifle No. 1,180,858 - Barrel badly eroded
Ammunition: Cal. .30 Ball M1, Lot 1342
Thermocouple Location: 0.8" ahead of forcing Cone
Air Temperature: 78° F.

Time of Rd. in Chamber	Temp. of Rifle	Bolt Lift	Firing Pin Position
min.	°C.	lbs.	
0	30	10	in
0	34	11	"
0	38	11	"
0	44	4	withdrawn
0	46	4	"
0	50	6	"
0	102	14	in
0	102	11	"
0	102	11	"
0	102	4	withdrawn
0	102	4	"
0	102	4	"
1/2	95	10	in
"	96	4	withdrawn
"	96	4	"
"	96	4	"
"	96	4	"
1	93	4	"
"	93	5	"
"	93	4	"
"	93	4	"
"	93	4	"
1-1/2	91	4	"
"	91	4	"
"	90	4	"
"	90	4	"
0	190	20	"
"	190	22	"
"	190	32	"
"	190	31	"
"	190	15	"
"	190	17	"

Time of Rd. in Chamber min.	Temp. of Rifle °C.	Bolt Lift lbs.	Firing Pin Position
1/2	179	4	withdrawn
"	178	4	"
"	178	4	"
"	178	5	"
"	178	4	"
1	170	4	"
"	170	14	in
"	170	12	"
"	170	4	withdrawn
"	170	4	"
1-1/2	164	14	in
"	164	14	"
"	164	6	withdrawn
"	163	5	"
"	161	15	in
2 min.	158	15	"
"	157	16	"
"	158	6	withdrawn
"	158	4	"
"	158	6	"
0 min.	200	63	in
"	200	34	"
"	200	31	withdrawn
"	200	20	"
"	200	35	"
1	188	14	in
"	177	14	"
"	178	5	withdrawn
"	178	4	"
"	178	4	"
2	167	17	in
"	165	16	"
"	165	6	withdrawn
"	165	4	"
"	165	4	"
With ammunition loaded for 15% Excess Pressure			
0	42	24	in
"	46	25	"
"	50	8	withdrawn
"	54	10	"

Table II

Bolt Lift Test, Sept. 8, 1936

Rifle No. 1,180,858 - Barrel badly eroded
Ammunition: Cal. .30 Ball M1, Lot 1342
Thermocouple Location: Over center of chamber
Air Temperature: 84° F.
Bolt lift measured with firing pin withdrawn

	Time of Rd. in Chamber	Rifle Temp. Round In °C	Rifle Temp. Round Out °C	Bolt Lift lbs.
1	44 sec. (pre-ignition)	150	149	0
2	4 min.	146	129	10
3	43 sec. (pre-ignition)	149	148	-
4	90 sec. (pre-ignition)	148	146	-
5	85 sec. (pre-ignition)	146	145	-
6	4 min.	147	132	29
7	45 sec.	151	152	16
8	3 min. 10 sec. (misfire)*	149	140	26
9	4 min.	138	120	13

* Fired either by pre-ignition or by gunner unintentionally pulling lanyard.

Table III

Bolt Lift Test, Sept. 15, 1936

Rifle No. 142,992
Thermocouple Locations: Over center of chamber and over forcing cone.
Ammunition: Cal. .30 Ball, M1, Lot 1342 and Lot 1684
Bolt lift measured with firing pin withdrawn

	Gauge Measurement	Time in Chamber	Temp. over Chamber °C	Temp. Forcing Cone °C	Bolt Lift lbs.
(a)	Ammunition Lot 1342, Fired Immediately				
1	.874	0 min.	104	180	30
2	.872	" "	106	161	27
3	.872	"	-	-	20
4	.856	"	-	-	17
5	.879	"	104	148	21
(b)	Ammunition of Lot 1684, Fired Immediately				
1	.832	"	100	140	41
2	.810	"	-	-	38
3	.853	"	-	-	41
4	.835	"	-	-	35
5	.860	"	97	136	41
6	.856	"	95	130	38
(c)	Ammunition of Lot 1342 soaked in chamber				
1	.864	4 min.	131 (rd. in) 116 (rd. out)	156 150	32
2	.875	94 sec. (pre-ignition)	135 (rd. in) 136 (rd. out)	230 201	18
3	.870	4 min.	134 120	192 153	20

Table III (cont'd)

Bolt Lift Test, Sept. 15, 1936

(d) Ammunition of Lot 1684 soaked in chamber

	Gauge Measurement	Time in Chamber	Temp. over Chamber °C	Temp. Forcing Cone °C	Bolt Lift lbs.
1	.820	82 sec. (pre-ignition)	136 (rd. in)	221	
			135 (rd. out)	198	48
2	.830	4 min.	135 (rd. in)	193	
			120 (rd. out)	152	92*
3	.827	2 min. (pre-ignition)	134 (rd. in)	216	
			129 (rd. out)	194	45
4	.854	4 min.	130 (rd. in)	200	
			122 (rd. out)	154	63

* Primer blown

Table IV

Bolt Lift Test, Sept. 25, 1936

Air Temperature: 66° F.
Location of Thermocouple: Over chamber and over forcing cone.
Rifle No. 142,992 - Maximum and minimum rounds.
Ammunition: Cal. .30 ball, M1, Lot 1342
Bolt lift measured with firing pin withdrawn

Rd. No.	Gauge Measurement		Time in Chamber	Temp. over Chamber °C	Temp. over Forcing Cone °C	Bolt Lift lbs.
1	.881"	(max. rd.)	0 min.	135	276	100
2	.881	"	"	137	268	96
3	.875	"	"	140	258	50
4	.879	"	"	140	251	90
5	.884	"	"	140	237	86
6	.825	(min. rd.)	"	140	219	100+
7	.822	"	"	137	212	62
8	.823	"	"	135	209	84
9	.820	"	"	140	284	63
10	.830	"	"	146	278	100+
11	.824	"	"	149	258	100+
12	.830	"	"	151	248	100+
13	.828	"	"	150	240	100+

Table V

Bolt Lift Test, Sept. 25, 1936

Air Temperature: 66° F.
Location of Thermocouple: Over chamber and over Forcing Cone.
Rifle No. 1,180,858 - Barrel badly eroded.
Ammunition: Cal. .30 Ball, M1, Lot 1684
Bolt lift measured with firing pin withdrawn

Rd. No.	Gauge Measurement	Time in Chamber	Temp. over Chamber °C	Temp. over Forcing Cone °C	Bolt lift lbs.
1	.821"	30 sec. (pre-ignition	135 (in) 137 (out)	274 252	17
2	.823"	70 sec. (pre-ignition)	136 (in) 132 (out)	224 206	13
3	.789"	4 min.	121 (in) 117 (out)	173 160	34
4	.810"	4 min.	117 (in) 99 (out)	160 129	30
5	.813"	102 sec. (pre-ignition)	125 (in) 132 (out)	252 212	22
6	.821"	4 min.	132 (in) 119 (out)	212 162	26
7	.803"	4 min.	119 (in) 102 (out)	162 131	16
8	.786"	3 min. 22 sec. (pre-ignition)	123 (in) 129 (out)	249 184	17
9	.802"	0 min.	153	258	100+
10	.828"	0 min.	153	246	100+
11	.797"	0 min.	152	236	100+

Table VI

Bolt Lift Test, Sept. 25, 1936

Air Temperature: 66° F.
Location of Thermocouple: Over chamber and over forcing cone.
Rifle No. 142992 - Bolt with ridge on face relieved at 45°
Ammunition: Cal. .30 Ball, M1, Lot 1342
Bolt lift measured with firing pin withdrawn

Rd. No.	Gauge Measurement	Time in Chamber	Temp. over Chamber °C	Temp. over Forcing Cone °C	Bolt Lift lbs.
1	.857	0 min.	134	199	84
2	.830	"	140	194	42
3	.840	"	137	192	51
4	.856	"	135	190	35
5	.835	"	133	189	59
6	.868	111 sec. (Pre-ignition)	131 (in) 133 (out)	230 200	4
7	.850	4 min.	133 (in) 121 (out)	200 156	21
8	.866	"	121 (in) 105 (out)	156 127	8
9	.860	"	121 (in) 122 (out)	212 161	14
10	.834	"	128 (in) 130 (out)	248 222	3
11	.865	"	130 (in) 120 (out)	222 168	7

Table VI (cont'd)

Bolt Lift Test, Sept. 25, 1936

Air Temperature: 66° F.
Location of Thermocouple: Over chamber and over forcing cone
Rifle No. 142,992 - Bolt with .01 inch milled off faces of locking lugs to increase headspace
Ammunition: Cal. .30 Ball, M1, Lot 1342
Bolt lift measured with firing pin withdrawn

Rd. No.	Gauge Measurement	Time in Chamber	Temp. over Chamber °C	Temp. over Forcing Cone °C	Bolt Lift lbs.
1	.843"	0 min.	130	253	100+
2	.855	"	141	231	41
3	.844	"	141	224	71
4	.837	"	140	216	96
5	.864	"	139	210	94
6	.852	"	137	206	12
7	.859	"	136	204	39
8	.870	"	136	202	100+
9	.875	"	135	200	63
10	.856	"	135	199	29
11	.862	"	134	196	76
12	.852	4 min.	131 (rd. in)	189	
			115 (out)	152	8
13	.862	2 min. 28 sec.	125 (in)	233	
		(pre-ignition)	131 (out)	198	7 ✓
14	.856	4 min.	131 (in)	198	
			118 (out)	149	8 ✓
15	.855	"	118 (in)	149	
			102 (out)	125	6 ✓
16	.845	80 sec.	125 (in)	241	
			133 (out)	214	10 ✓
17	.846	4 min.	133 (in)	214	
			127 (out)	165	23 ✓
18	.866	"	127 (in)	165	
			113 (out)	136	16 ✓

Table VII

Stargauge Measurements
Springfield Rifle No. 1180858, Centrilite
After 11,830 Rounds 9/14/36

Lands	Grooves
.3015	.3085
.3015	.3080
.3020	.3080
.3020	.3080
.3025	.3080
.3030	.3080
.3035	.3080
.3040	.3080
.3040	.3080
.3045	.3085
.3050	.3085
.3055	.3085
.3060	.3085
.3070	.3090
.3070	.3090
.3070	.3095
.3070	.3100
.3075	.3105
.3080	.3110
.3090	.3115
.3100	.3120
.3110	.3125
*	.3130

* Beyond the range of the stargauge.

Table VIII

Pressures and Velocities for Heated Ammunition
Fired October 6, 1936

Ammunition: Cal. .30, M1 Ball, Lot 1342, Service Charge

Rd. No.	Copper Pressures lbs/in²	Piezo-Electric Pressures lbs/in²	Velocity ft/sec	Temperature of Ammunition °C
1	35,500	41,800	2524	23.5
2	35,900	40,400	2515	23.5
3	49,800	54,100	2748	101
4	52,400	58,700	2765	100
5	52,850	56,600	2785	110
6	56,900	62,600	2816	115

Same Fired October 7, 1936

Rd. No.	Copper Pressures lbs/in²	Piezo-Electric Pressures lbs/in²	Velocity ft/sec	Temperature of Ammunition °C
1	61,600	63,600	2820	123
2	58,900	63,700	2813	130
3	61,900	64,100	2788	134
4	68,050	68,800	2848	134
5	64,900	75,200	No timing lines	136
6	47,000	50,200	2627	23.4

RESUME

A. Tests

1. Bolt lift was measured for

   a. Cold rounds in a hot gun,
   b. Rounds loaded to produce 15% excess pressure,
   c. Hot rounds in a hot gun,
   d. Two grades of ammunition, one of service quality and the other labelled High Fxtraction,
   e. Rounds of minimum and maximum case diameter in a hot gun,
   f. A new gun and a badly eroded one, and
   g. Two modified bolts.

2. Piezo-electric gauge records were made by firing ammunition heated in an oven in a pressure gun.

B. Results

1. Maximum bolt lift was obtained for cold rounds fired in a hot gun.

2. A charge designed to produce 15% excess pressure increased the bolt lift over that produced by the service charge.

3. Lower bolt lifts were obtained for rounds soaked four minutes in a hot gun before being fired than for rounds fired immediately upon being chambered in a hot gun.

4. Deformation of the cases of the High Fxtraction ammunition was greater than that of the ammunition of service quality.

5. Although minimum cartridges may have shown a tendency to give higher bolt lifts, an interpretation of the data cannot be made with any assurance because of the variation of gun temperature.

6. For hot rounds soaked in a hot gun bolt lift was lower in the worn Springfield than in the new one.

7. The modified bolts may have shown a tendency to give higher bolt lifts, but variation in temperature between tests makes interpretation of the data difficult.

8. The Piezo-electric gauge records of hot rounds show no evidence of pressure waves.

C. Inferences from the Tests

1. High bolt lifts are obtained when cartridges are fired immediately upon being chambered in a hot gun because increase in clearance between the case and the chamber increases the possible deformation of the case.

2. Bolt lift is higher for a round soaked four minutes in a hot gun before being fired than for a cold round fired in a cold gun because the pre-heating of the charge increases the combustion rate and hence the maximum pressure developed by the charge.

3. The high pressures developed by the charges of heated rounds are due to more rapid combustion in the normal way and not to reinforcement of the maximum pressure by a pressure wave.

4. Decreasing the clearance between the case and the chamber should make extraction less difficult under conditions of delayed firing in a hot gun because it will make pre-ignition of the charge more probable, which will tend to limit the average temperature of the charge.

5. The extraction characteristics of any new rifle can probably be improved by removing enough metal from the bore at the origin of the rifling to simulate the erosion present in a worn gun.

6. It appears that, other things being equal, bolt lift may be expected to be a minimum for any given firing conditions if the clearance between the cartridge and the chamber is a minimum and if the chamber is as long as the proper functioning of the extractor will permit.

SUMMARY OF COMPARABLE BOLT LIFT DATA

(1) Cold Rounds in Hot Gun

Table No.	Barrel	Bolt	Ammunition	No. Rds.	Chamber Temp. Max. °C	Chamber Temp. Min. °C	Chamber Temp. Av. °C	Time of Rd. in Chamber	Bolt Lift lbs. Max.	Bolt Lift lbs. Min.	Bolt Lift lbs. Mean
I	Worn	Normal	Regular (Lot 1342)	6	120(?)	120(?)	120(?)	0	32	15	23
V	"	"	High Extraction (Lot 1684)	3	153	152	153	0	100+	100+	100+
III	New	"	Regular	5	106	104	105	0	30	17	23
III	"	"	High Extraction	6	100	95	97	0	41	35	39
VI	"	Ridge Relieved	Regular	5	140	133	136	0	84	35	54
VI	"	Head Space increased 0.01"	Regular	11	141	133	136	0	100+	12	66

Cold rounds in warm gun

Table No.	Barrel	Bolt	Ammunition	No. Rds.	Chamber Temp. Max. °C	Chamber Temp. Min. °C	Chamber Temp. Av. °C	Time of Rd. in Chamber	Bolt Lift lbs. Max.	Bolt Lift lbs. Min.	Bolt Lift lbs. Mean
I	Worn	Normal	Regular	3	50	44	47	0	6	4	5

(?) = Temperature Estimated from Forcing Cone Temp.; Chamber Temp. not measured.

SUMMARY OF COMPARABLE BOLT LIFT DATA

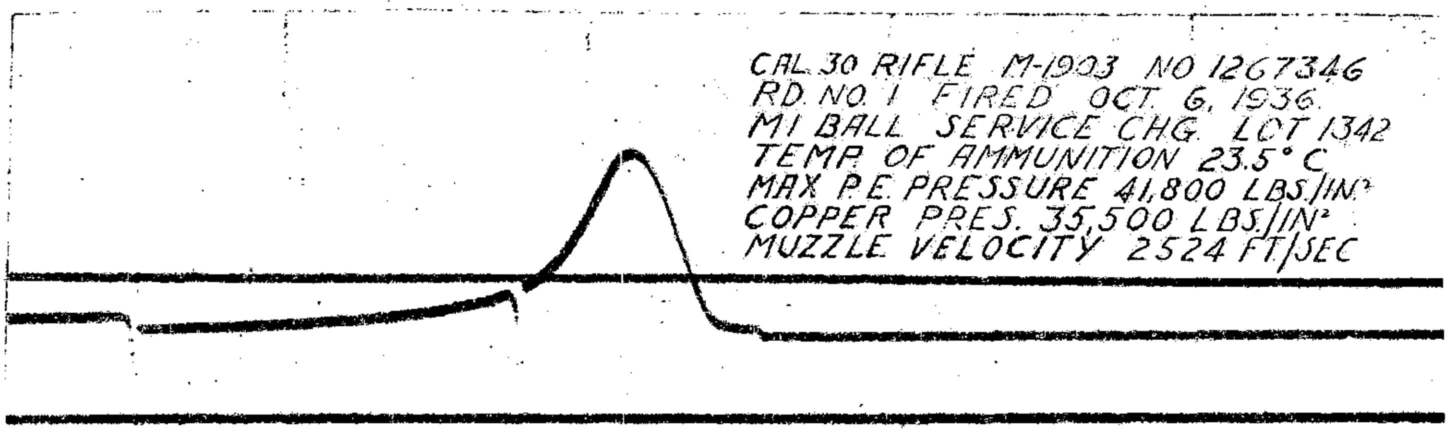
(2) Hot Rounds in Hot Gun

Table No.	Barrel	Bolt	Ammunition	No. of Rds.	Chamber Temp. Max. °C	Chamber Temp. Min. °C	Chamber Temp. Mean °C	Time of Rd. in Chamber	Bolt Lift lbs. Max.	Bolt Lift lbs. Min.	Bolt Lift lbs. Mean
II	Worn	Normal	Regular	3	147	120	135	4 min.	29	10	17
V	"	"	High Extraction (Lot 1684)	4	132	99	118	"	34	16	27
III	New	"	Regular	2	134	116	125	"	32	20	26
III	"	"	High Extraction	2	135	120	132	"	92	63	78
VI	"	Ridge relieved	Regular	5	130	105	123	"	21	3	11
VI	"	Head space increased 0.01"	Regular	5	133	102	122	"	23	6	12

SUMMARY OF COMPARABLE BOLT LIFT DATA

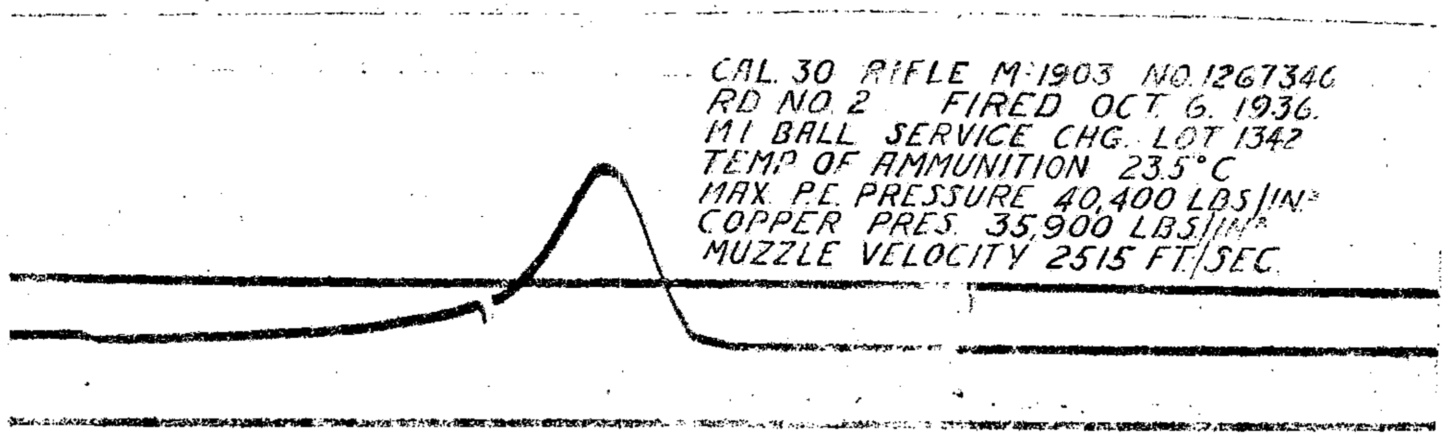
(3) Rounds which Pre-Ignited

Table No.	Barrel	Bolt	Ammunition	No. of Rds.	Chamber Temp. Max. °C	Chamber Temp. Min. °C	Chamber Temp. Av. °C	Average Time of Rd. in Chamber	Bolt Lift - lbs. Max.	Bolt Lift - lbs. Min.	Bolt Lift - lbs. Av.
II	Worn	Normal	Regular Lot 1342	2	152	149	151	44 sec.	16	0	8
V	"	"	High Extraction Lot 1684	4	137	123	131	101 "	22	13	17
III	New	"	Regular	1	136	135	136	94 "	-	-	18
III	"	"	High Extraction	2	136	129	134	101 "	48	45	47
VI	"	Face Relieved	Regular	1	133	131	132	111 "	-	-	4
VI	"	Head Space Increased	"	2	133	125	129	114 "	10	7	9



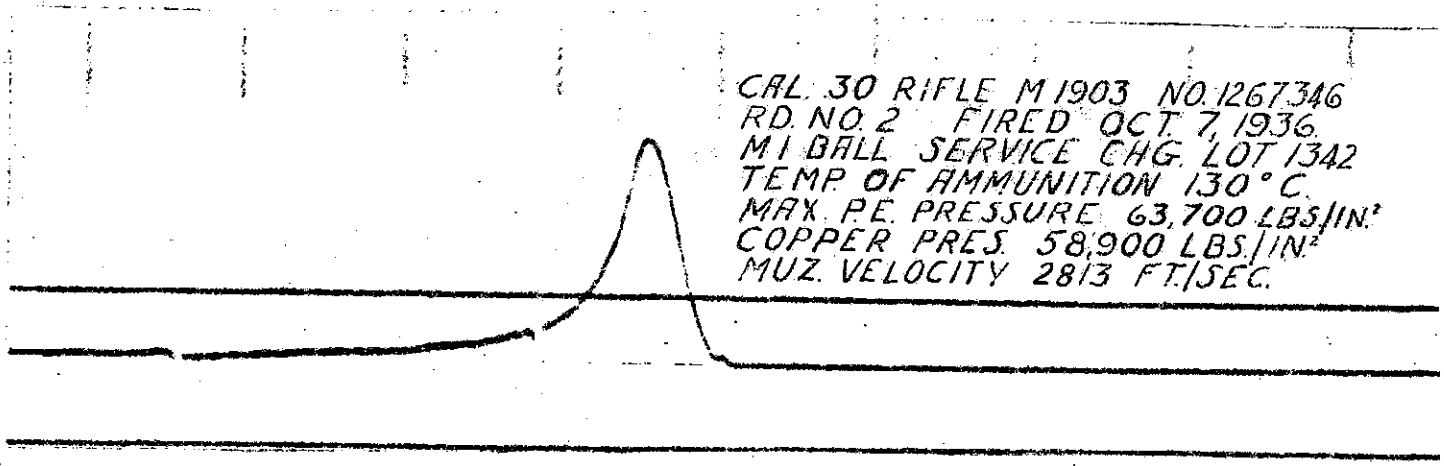
TEMP. OF AMMUNITION -23.5° C.

FIG. I



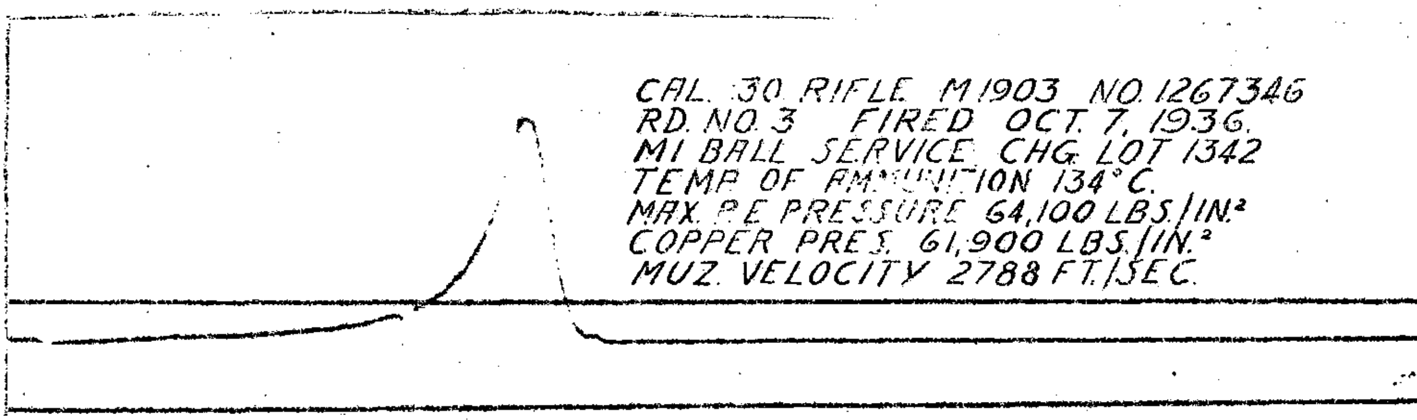
TEMP. OF AMMUNITION - 23.5° C.

FIG. II



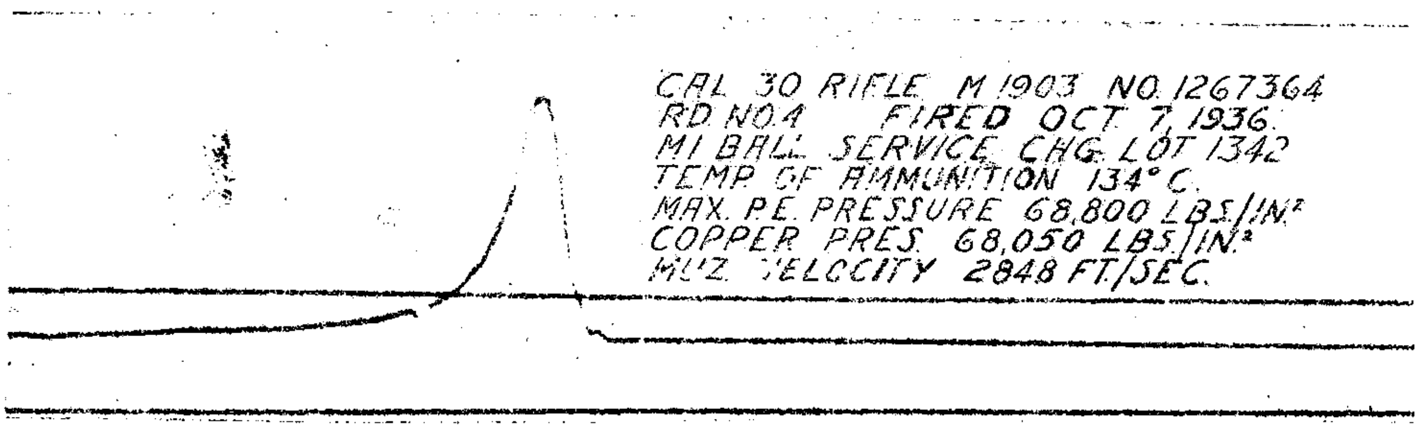
TEMP. OF AMMUNITION - 130° C.

FIG. III



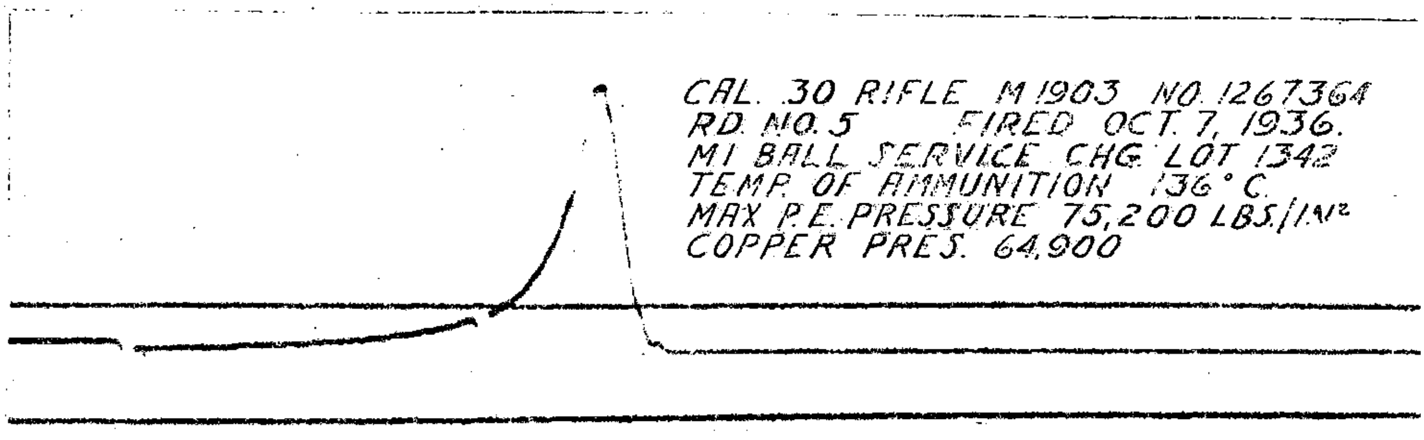
TEMP. OF AMMUNITION - 134° C.

FIG. IV



TEMP. OF AMMUNITION - 134° C

FIG. V



TEMP. OF AMMUNITION - 136° C.

FIG. VI